Advanced Simulation Capability for Environmental Management

Fiscal Year 2013 Annual Report

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ASCEM

The Advanced Simulation Capability for Environmental Management Initiative is funded by the U.S. Department of Energy Office of Environmental Management

Message from the Office Director and Program Managers

Protecting the nation's water resources for current and future generations is one of the missions of the U.S. Department of Energy (DOE) Office of Environmental Management (EM). Through the Advanced Simulation Capability for Environmental Management (ASCEM) Initiative and companion Applied Field Research Initiatives, the Office of Soil and Groundwater Remediation is working to deliver transformational science and technology-based solutions to complete the EM cleanup mission. Advanced simulation capabilities are critical for enabling the cleanup mission with cost-effective and sustainable solutions that protect human health and the environment. Through the collaborative efforts of diverse staff from the national laboratories, the ASCEM team made excellent progress in fiscal year (FY) 2013, leading to the recent release of a research version of ASCEM to end users for evaluation and feedback.

ASCEM's modular and open source toolsets facilitate integrated approaches to modeling and site characterization that enable robust and standardized assessments of performance and risk for EM cleanup and closure activities. Specifically, the ASCEM initiative is aimed at addressing critical EM program needs to better understand and quantify 1) the subsurface flow and contaminant transport behavior in complex geological systems; 2) long-term performance of engineered components including cementitious materials in nuclear waste disposal facilities; and 3) uncertainties and risks associated with EM's environmental cleanup and closure programs. ASCEM will also help transform fundamental science innovation into practical applications deployed by site contractors across the entire DOE complex and is being integrated with the emerging EM endpoints initiative.

The ASCEM initiative is expected to continue to make significant progress in capability development, leading to release of an applied version of the toolset with higher-level quality assurance at the end of 2014, and a version qualified for regulatory applications in 2015.

Kurt Gerdes
Director, Office of Soil and Groundwater Remediation
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Responding to the Challenge

In their 2009 report, "Advice on the Department of Energy's Cleanup Technology Roadmap: Gaps and Bridges," the National Research Council (NRC) of the National Academies reviewed and validated the U.S. Department of Energy (DOE) Office of Environmental Management (EM) Technology Program. The NRC report outlined prioritization needs for the Groundwater and Soil Remediation Roadmap, and concluded that the complexity and magnitude of the DOE environmental problem justifies long-term investment in environmental remediation science and technology, including predictive capabilities. To address the investment need, EM funded a number of initiatives in 2010, including a strategic initiative in the Office of Soil and Groundwater to develop the Advanced Simulation Capability for Environmental Management (ASCEM). ASCEM is a state-of-the-art scientific approach that uses an integration of toolsets to understand and predict contaminant fate and transport in natural and engineered systems. The modeling toolset is modular and open source and is divided into three thrust areas: Multi-Process High Performance Computing (HPC), Platform and Integrated Toolsets, and Site Applications (Figure 1). The toolset facilitates integrated approaches to modeling and site characterization that enable robust and standardized assessments of performance and risk for EM cleanup and closure activities.

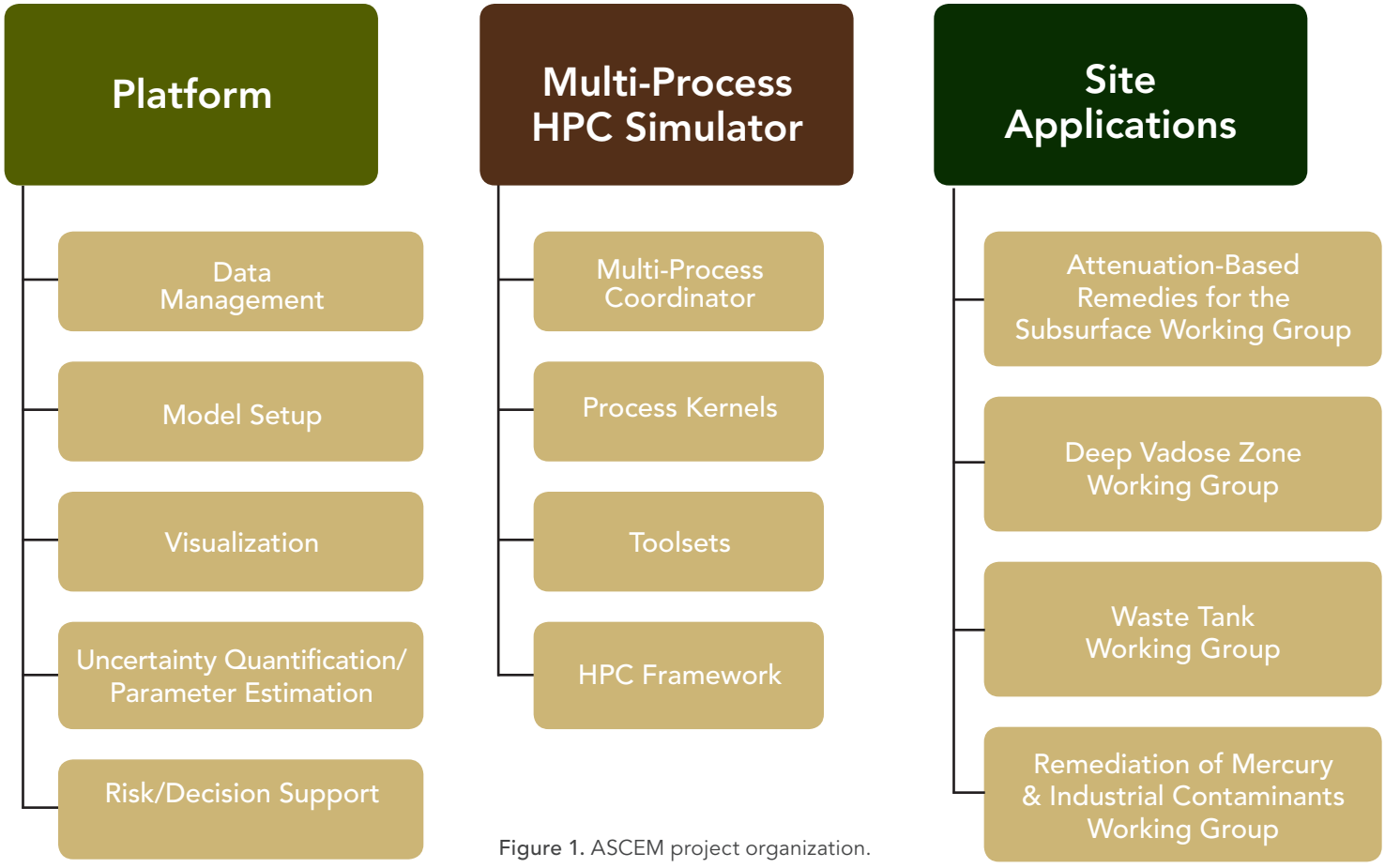

Figure 1. ASCEM project organization.

[1]National Research Council. 2009. *Advice on the Department of Energy's Cleanup Technology Roadmap: Gaps and Bridges*. National Academies Press, Washington, D.C. Available at http://www.nap.edu/catalog.php?record_id=12603.

Communication of Phase II Demonstration Results

Significant development of ASCEM and demonstration of integrated capabilities occurred in fiscal year (FY) 2012 and the first quarter of FY 2013. Results of the demonstration were communicated through a series of briefings at EM Headquarters and field offices as well as the DOE Office of Science (SC). The briefings focused on the Phase II Demonstration, including an end-to-end application of capabilities at the Hanford Site deep vadose zone (BC Cribs and Trenches). Other aspects of the Phase II Demonstration that were highlighted included addressing attenuation-based remedies at the Savannah River Site (SRS) F Area and detailed advanced modeling simulations of a representative waste tank. In addition, new ASCEM hydrology capabilities were showcased in a demonstration at the Nevada Nuclear Security Site (NNSS). A major outcome is a plan for stronger teaming with the SC Climate and Environmental Sciences Division on EM science issues in the subsurface.

Capability Development

Significant development of capabilities occurred on both the Platform (Akuna) and HPC (Amanzi) thrust areas of the project during FY 2013. The Platform and Integrated Toolsets Thrust enhanced the user interface and tools for site data management, model setup, model calibration and uncertainty analysis, and model results visualization. The HPC Simulator increased the functionality of its process model representations, toolsets for interaction with the Platform, model confidence testing, and verification for quality assurance. A focused effort resulted in release of a research version of the ASCEM toolset to end users for evaluation and feedback.

Akuna

The Platform and Integrated Toolsets Thrust focused development activities on effective and robust integration among the Akuna, Agni, and Amanzi tools. A key element of this integration is a new Extensible Markup Language (XML) Amanzi input file specification and schema. An XML schema is a document that describes the structure of and rules that apply to an XML file. The XML input file provides a framework for automated validation of input files and a well-defined specification for the file format that is agreed upon by personnel in all thrust areas. This new input file format and schema has been developed in close coordination with the HPC and Site Applications thrust areas and with input from a broad spectrum of the ASCEM team. A parallel specification for the Agni input file has also been developed. The tools that read and write files in Akuna, Agni, and Amanzi were refactored to accommodate the new specification and ensure that all three elements can interface robustly and effectively. The Akuna user interface (UI) was updated to reflect changes in the input file specification and structure, and to address deficiencies identified in previous testing. The new input file format specification, schema, and validated instance files, Amanzi input file reader/writer/validator, and Agni input file writer have all been completed. The Akuna user environment is depicted in Figure 2.

A second key element of this integration is coordinated testing, which for the platform tools encompasses two phases: 1) integration testing, to ensure that the interfaces described above work effectively, and 2) user testing, to ensure that the Akuna UI is readily usable and intuitive, and that any major bugs have been identified and addressed. User testing in this phase includes testers from Pacific Northwest National Laboratory, Lawrence Berkeley National Laboratory, Los Alamos National Laboratory, and Savannah River National Laboratory to ensure that

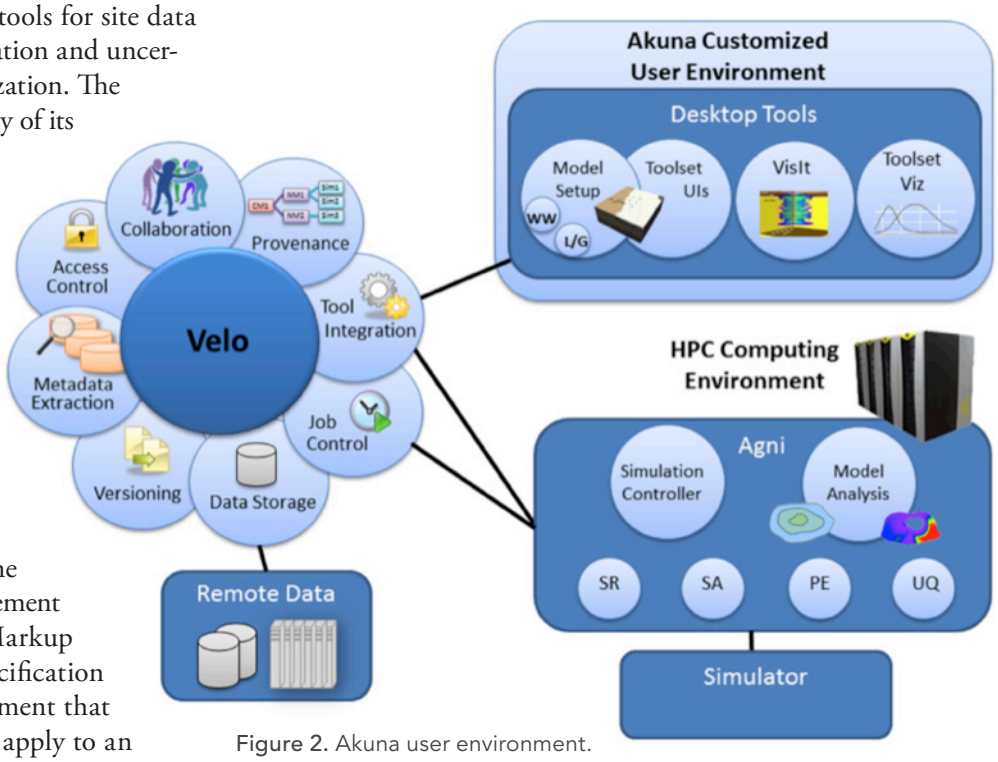

Figure 2. Akuna user environment.

the ASCEM products have a broad internal user base prior to external release. The following Akuna capabilities have been developed for the release:

- Implementation of the new XML file format and schema, with interactive file validation.
- Incorporation of Amanzi capabilities in the Akuna UI model setup tool.
- Integration with Agni and Amanzi, including options to work directly with raw input files or build input files through the Akuna model setup UI.
- Direct linkage of the data management platform and interactive VisIt visualization.

The Data Management toolset made advances in depth-time visualization tools, and these will be tested/demonstrated using output from the Site Applications Thrust demonstration problems. Finally, Agni regression tests have been developed that examine the Model Analysis and Decision Support (MADS) interface, execution of a forward run, as well as the Sensitivity Analysis (SA), Parameter Estimation (PE), and Uncertainty Qualification (UQ) toolsets.

Amanzi

The HPC Thrust focused development activities on improving performance and robustness of Amanzi, as well as enhancing capabilities for the initial release. In collaboration with the Platform and Site Applications thrust areas, a new XML schema was developed for the input specification to improve the robustness of the Akuna/Amanzi coupling as well as to significantly enhance the usability of Amanzi. In preparation for the three-dimensional F-Area conceptual models with barriers and wells targeted for Phase III, development and testing was performed on fully unstructured prismatic and mixed prismatic/hexahedral meshes. In addition, more flexible interfaces to nonlinear and linear solvers were developed, and more robust optimization of mimetic finite difference schemes as well as more efficient two-point flux based schemes were added. Finally, an interface and library named Alqumia was developed to allow Amanzi to use existing, mature geochemistry software as process kernels. This application programming interface (API) provides access to advanced features of these established tools, such as complex geochemical conditions at boundaries and advanced high-ionic strength chemistry models (e.g., Pitzer) for waste tank scenarios and engineered barriers. In addition, the API encourages more active collaboration with geochemists and computational geoscientists who have already implemented specialized reaction networks and models that they would like to use with Amanzi's flexible flow and transport capability.

Documentation of Amanzi for this release includes a user guide describing how to obtain, install, and use Amanzi. The user guide features a tutorial that provides an overview of key elements of the new XML input specification through working examples, as well as a collection of well-established verification tests for transient and steady-state flow and transport. An important feature of this documentation is that it uses the Sphinx documentation generator to continually rebuild the user guide as new tutorials and tests are added. Moreover, the documentation of each test is rebuilt, with output from the current build of Amanzi. This automated approach helps developers ensure that Amanzi is functioning properly and synchronizes the user guide with the most recent code development. The following capabilities for this release of Amanzi are available through Akuna:

- Transient unsaturated flow with Richards equation, and single-phase flow with specific storage/yield, including volume based sources for basins and wells.
- Non-reactive advection-dispersion transport of chemical species with flow-aligned dispersion tensors in steady state or transient, variably saturated or fully saturated, flow fields.
- Unstructured meshes with polyhedral cells (i.e., prism, hexahedral, or more general shapes) and internal generation of hexahedral meshes in rectangular domains.
- Parallel input/output including visualization, restart, and checkpoints.
- Flexible and easy to read XML input designed to integrate with Akuna model setup and toolsets.

Capabilities available in Amanzi through its first generation input specification include:

- Block-structured adaptive mesh refinement (AMR) for front-tracking and grid-aligned engineered features (includes internal grid generation for rectangular domains).
- Reactive transport, with support for a wide range of chemical reactions, including 1) equilibrium aqueous complexation and surface complexation; 2) mineral precipitation–dissolution (transition state theory); and 3) sorption isotherms (K_d, Langmuir, Freundlich).
- Prototype of Alquimia, the unified API and library for interfacing Amanzi with existing biogeochemistry software (e.g., PFLOTRAN, CrunchFlow, PHREEQE, Amanzi, TOUGH).

Development in 2014 will make these latter capabilities available through Akuna.

Testing and Application

Working groups made progress on testing and application of the ASCEM toolsets to EM-relevant problems. Initial efforts focused on furthering the Phase III Demonstration, but later in the fiscal year, the focus shifted to testing in support of the initial release of ASCEM. The Site Applications Thrust activities focused on the following sites:

- **SRS F Area.** The team 1) developed new conceptual models of the site including the past and current engineering treatments performed for remediation (e.g., pump and treat, funnel-and-gate system) and facies-based subsurface heterogeneity (shown in Figure 3), 2) identified capabilities that need to be developed to carry out the demonstration, 3) acquired new site datasets needed for demonstration, particularly those associated with engineering treatments (i.e., barrier geometry), and 4) developed a detailed plan for the demonstration based on the feedback from the Platform and HPC teams. The new capabilities include more-efficient three-dimensional simulations, improved robustness to include engineered structures having sharp contrasts in hydraulic properties, heterogeneity of flow and reactive-transport properties, wellbore-delivered remediation treatments, random field generation of flow and reactive-transport property fields, and incorporation of geochemistry interface (Alquimia). The demonstration plan also includes communication with the F-Area operations staff to assess existing and new remediation strategies.
- **User Release.** For the user release, the Site Applications Thrust developed benchmarking and tutorial problems, focused on setting up suites of modeling tasks (i.e., model set up, simulation, UQ, visualization) using the F-Area Seepage Basins, BC Cribs at the Hanford Site (Figure 4), and representative waste tank problems. The team also tested various capabilities in the HPC and Platform thrust areas.
- **NNSS.** Underground Test Area Program (UGTA) personnel at NNSS have been working closely with the ASCEM team to develop a modeling capability to predict and characterize reactive flow and transport in the fractured volcanic rocks on Pahute Mesa, where the majority of the NNSS underground radionuclide inventory resides. The Amanzi code was enhanced by the addition of specific capacity and specific discharge capabilities, allowing evaluation of existing pump test data. A series of benchmark test calculations were run to show that the University of Nevada, Las Vegas (UNLV) computing system could be used to execute ASCEM with unclassified UGTA data. Completion of this testing allows full development of a benchmark problem using ASCEM for generating UGTA-relevant results on the UNLV system.

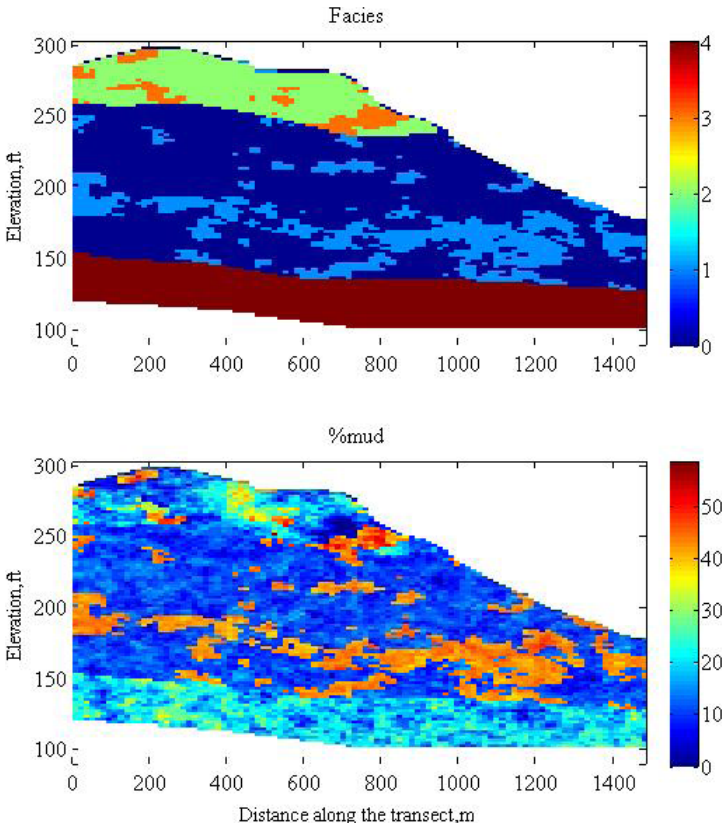

Figure 3. Facies-based heterogeneous field from conditional stochastic simulations at the 2D cross section parallel to the flow direction in the SRS F-Area: (a) heterogeneous facies field with facies labels and (b) %fine computed based on the facies.

User Release November 2013

The ASCEM toolset and tutorials will be released to an initial set of users in November 2013 for testing and evaluation. To meet quality assurance (NQA-1) requirements, ASCEM development follows a risk-based graded approach that uses three phases of development. The November 2013 release represents the Research and Development (R&D) branch corresponding to the initial NQA-1 "Basic Phase." This R&D branch release cannot be used for regulatory applications.

The November 2013 ASCEM toolset release will include Akuna (user interface), Amanzi (the simulator), and Agni (a set of tools for controlling the simulator). Web links for downloading executable files and the tutorial problems will be made available at http://ascemdoe.org, which points potential users to other sites where the files can be downloaded. Access will be granted to computing facilities (NERSC Hopper Cray XE6) to facilitate code testing and evaluation.

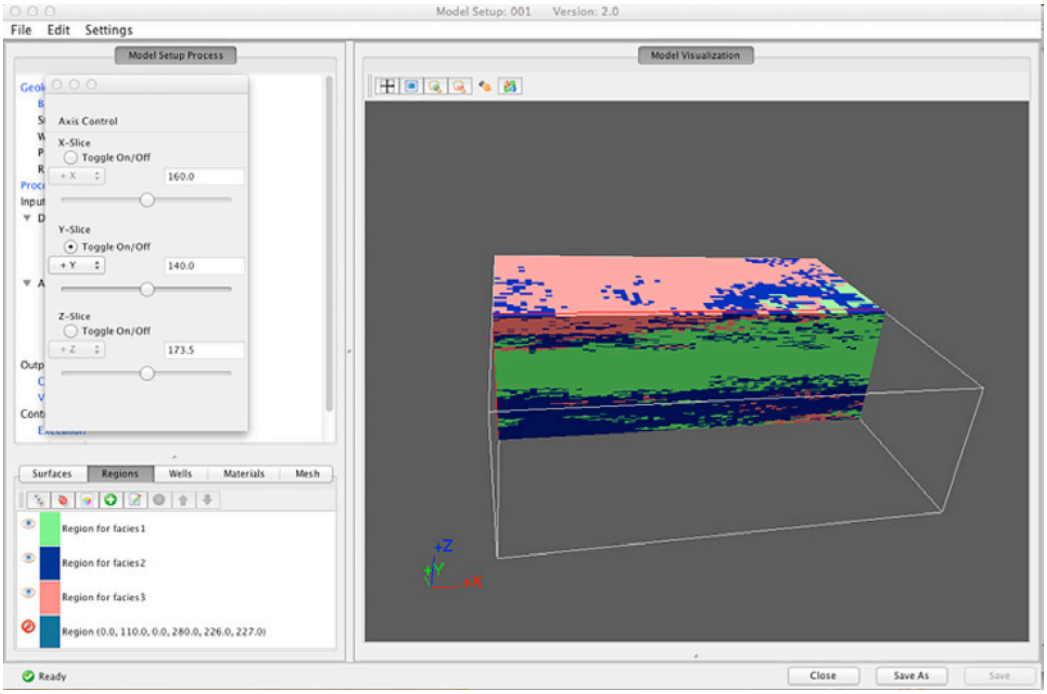

Figure 4. Viewer in the Model Setup and Analysis Tool showing the distribution of lithofacies.

External Interactions

The ASCEM initiative includes activities to maintain close contact with future end users of the tools. Engagement with the user community is viewed as critical to adoption of the tools. The engagement occurs through presentations to key user groups and direct interactions with individual users to seek input regarding specific needs. Key interactions from FY 2013 include the following:

- **Low-Level Waste Disposal Facility Federal Review Group (LFRG).** The ASCEM team continued efforts to provide updates on ASCEM progress at semi-annual business meetings for the LFRG, which includes key users from the EM performance assessment community
- **Performance Assessment and Risk Assessment Users.** ASCEM team members continued direct interactions with individual users, management and oversight personnel at DOE field offices, and contractors to obtain feedback about capabilities and current activities
- **Citizen's Advisory Boards.** The ASCEM team continued interactions with the SRS Citizens Advisory Board Facilities Disposition and Site Remediation Committee with a formal presentation that addressed the role of ASCEM for improved decision-making and improving the use of models for communication with regulators and the public. Interactions also continued with the Hanford Communities and the Hanford Advisory Board, River and Plateau Committee, where results for the BC Cribs demonstration were presented (Figure 5). Positive feedback resulted from these interactions.
- **Tribal Nation/Oregon Department of Energy Meeting.** Representatives from the ASCEM team presented Phase II Demonstration results for BC Cribs to Tribal Nations and DOE. Attendees expressed interest in accessing ASCEM when it is released.
- **Advanced Computing Technical Team.** DOE Headquarters staff actively participates and presents at bimonthly advanced computing meetings that encourage collaboration and information sharing between DOE offices.
- **Interagency Steering Committee on Multimedia Environmental Models (ISCMEM).** DOE Headquarters staff presented an update of Platform development at the ISCMEM meeting in Reston, Virginia.
- **Nuclear Safety Institute of the Russian Academy of Sciences.** Through the EM International Program, ASCEM HPC development was supplemented with expertise from the Russian Academy of Sciences.
- **SC-BER Subsurface Biogeochemical Research.** ASCEM staff began working with SC program managers to initiate a new project (funded by SC) to integrate earth systems simulation capabilities (namely the Community Land Model) into the Akuna platform and demonstrate ASCEM UQ capabilities using the Next-Generation Ecosystem Experiments Arctic field research site as a use case.

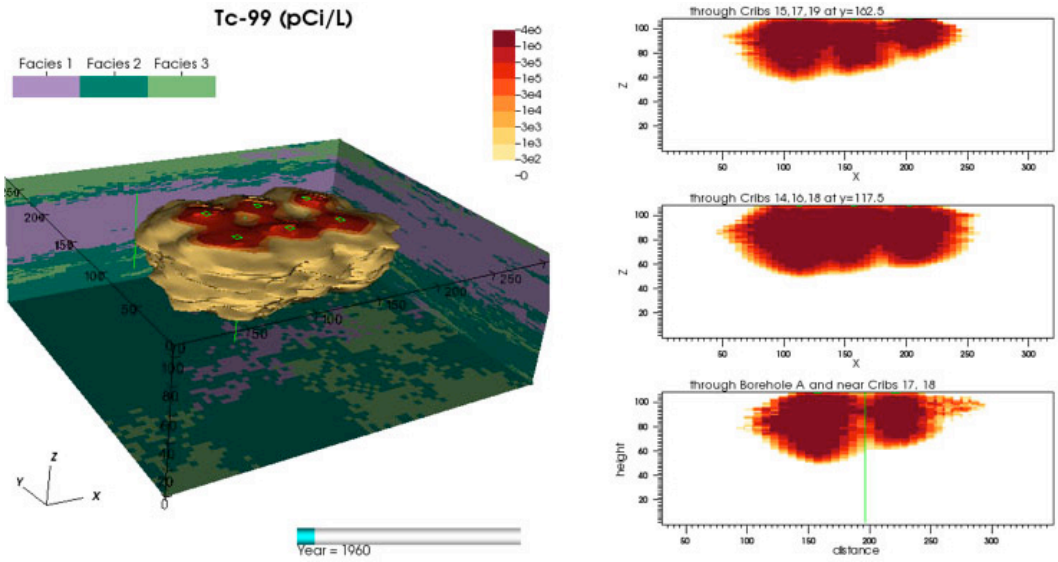

Figure 5. Spatial Distribution of Tc-99 after the releases from the BC cribs using VisIt software.

User Steering Committee

The ASCEM initiative conducts regular interactions with a User Steering Committee, which was established as part of the ASCEM team to promote adoption of the ASCEM tools. The committee consists of representatives from EM, field offices, site contractors, and regulatory agencies. The User Steering Committee provides suggestions and recommendations from an implementation perspective, focused on the importance of actively engaging the user and regulatory communities using the ASCEM tools and supporting opportunities to test the tools in parallel with existing applications. Such engagement can be included in a testing program and will provide an opportunity for direct experience with ASCEM to demonstrate its value compared to existing practice.

FY 2014 Planned Activities

The EM Office of Soil and Groundwater is supporting an endpoint framework that will support resolution of difficult environmental problems across the DOE complex. The framework will enable application of systems-based assessments and decision support and is based on establishing and evaluating robust conceptual site models. The ASCEM toolset will be integral to implementing the endpoint framework.

During FY 2014, the ASCEM initiative will continue development and outreach efforts to engage end users with the initial release. The focus will be on increasing robustness of the current toolsets through testing and quality assurance along with limited development and implementation of new capabilities. These goals will be accomplished through the following structured tasks. The activities in these tasks are closely coordinated to ensure commonalities are addressed and the software architecture supports a broad set of capabilities.

ASCEM uses a graded approach to quality assurance to develop in stages a fully NQA-1 compliant integrated tool suite, currently targeted for release in late 2015. The initial user release was developed following the requirements for the first phase (Basic Phase) of NQA-1 software quality assurance. During 2014, the project will will develop the requirements for the second phase (Applied Phase).

Platform and Integrated Toolsets

- The existing data management infrastructure will be enhanced to support modeling and analysis activities and increase integration with visualization tools. Integration with other Platform toolsets will be updated and capabilities to link with other data interfaces such as the PHOENIX (PNNL Hanford Online Environmental eXchange) tool for Hanford BC Cribs and the Restful interface to the data system from Akuna will be explored.
- The Model Setup toolset will be improved for usability, robustness, and performance, based on testing by the user community.
- Akuna release will be updated to improve user workflows, model management, and visualization. Working with the toolsets and Model Setup tasks, capabilities for users to exploit algorithms that are available in the toolsets will be improved. Attention will be given to performance and usability of the environment, as well as supporting initial users with documentation, case studies, and training.

- The Parameter Estimation toolset will be tested and included as an update to the initial user release. Enhancements will be evaluated and included to the extent possible to provide users with a broader range of capabilities that can be used in conjunction with Amanzi and Akuna to execute models and analyze results.
- Agni provides scalable and extensible coupling between the Akuna UI and Amanzi by managing model input and output to the simulators. In addition to executing a single simulation run, Agni executes a series of model analysis tools, including parameter estimation, geostatistical simulation, and uncertainty quantification. Agni's robustness and performance will be improved. A current need is the ability to coherently restart from any toolset run. Emphasis will be placed on ensuring seamless integration with Akuna, extending existing features to provide powerful and flexible tools for simulation execution and analysis.

High-Performance Computing

- In collaboration with the Platform and Site Applications thrust areas, the geochemistry sections of the XML input schema and specification will be developed. HPC Thrust personnel will collaborate on the design of the UI that is developed in Akuna. Finally, the integration of Alquimia in Amanzi will be enhanced for geochemistry. Workflow for geochemical conditions in boundary conditions and source terms will be improved.
- Access to the structured AMR mesh framework from Akuna will be re-established. Although there are no significant differences in the model description, expert parameters governing adaptivity of the mesh, discretization, and solvers are different and need special consideration.
- A flexible particle tracking capability for contaminant transport in fractured and highly heterogeneous rock will be integrated. Prototype work performed outside of ASCEM demonstrated that a particle tracking code could be driven by flow fields computed by Amanzi. This capability will be integrated, making it available through Akuna.
- Additional verification and benchmark tests will be developed and documented in the user guide. Software quality metrics, such as code coverage, and performance will be added to the documentation. In addition, the automated testing and reporting will be enhanced, including re-establishing tools to continuously track portability of code updates, and integration of the complete test suite to enable complete reporting to a web-based dashboard.

Site Applications

- Focused user interactions will be conducted around the EM complex to support the initial user release, including face-to-face meetings with site contractors and DOE staff. These discussions will occur at SRS and the Hanford Site, with smaller, focused interactions at other sites including NNSS.
- The ASCEM toolsets will be made available for public release and a notice forwarded to potential end users. Possible other targeted groups include the User Steering Committee and representatives from federal and state regulatory agencies.
- Working group activities have shifted from large-scale demonstration problems that have helped guide initial ASCEM development to testing and limited collaborative efforts with EM sites on relevant problems. The Site Applications working group members provide the core of internal testing for ASCEM with direct feedback to the development teams.
- Collaboration with the Nevada Nuclear Security Site UGTA will continue, focused on developing a benchmark problem for testing the EM Amanzi code against analytical solutions relevant to the site. The benchmark problems will entail heterogeneous systems composed of zones with contrasting aquifer properties; heterogeneous zones with circular and linear shapes near the pumping well will be investigated using the well-established analytical solutions. A demonstration will be developed using the parameter estimation toolset and used to calibrate flow models based on alternative conceptualizations. Parameter sensitivities will be investigated using Akuna's toolset and an uncertainty analysis performed to enable UGTA staff to suggest changes to the interface and capabilities. As a test problem, this effort can also give other UGTA staff experience in HPC simulations with Amanzi.
- The Project Management Thrust will continue the activities of the User Steering Committee, communications, project controls and reporting, and quality assurance implementation. The User Steering Committee will meet to provide feedback to the ASCEM team.
- Infrastructure for communication including website management will be maintained for ASCEM. The communications function will support regular communication products, including input to EM weekly reports, EM highlights, and annual reports.

- To ensure NQA-1 compliance, a graded approach is being implemented to allow for early development and testing of prototype components and systems without unnecessary burden on the research and development effort. Other software quality standards such as the 1996/1997 EPA Guidance, "Ground-Water Model Testing: Systematic Evaluation and Testing of Code Functionality and Performance," and ASTM D 6025 (reapproved 2008), "Standard Guide for Developing and Evaluating Groundwater Modeling Codes," will be considered for application, depending on regulatory requirements. As components and systems mature to deployment status, enhanced quality assurance requirements and corresponding procedures will be applied.

Publications and Presentations

ASCEM actively participates in the technical community. The following presentations and publications resulted from ASCEM efforts:

Freshley M, S Hubbard, G Flach, V Freedman, D Agarwal, B Andre, Y Bott, X Chen, J Davis, B Faybishenko, I Gorton, C Murray, D Moulton, J Meyer, M Rockhold, A Shoshani, C Steefel, H Wainwright, and S Waichler. 2012. *Phase II Demonstration*. ASCEM-SITE-2012-01, U.S. Department of Energy, Office of Environmental Management, Washington, DC

Bea S, H Wainwright, N Spycher, B Faybishenko, SS Hubbard, and M Denham. 2013. "Identifying key controls on the behavior of an acidic-U(VI) plume in the Savannah River Site using reactive transport modeling," doi:10.1016/j.conhyd.2013.04.005 (in press).

Freedman VL, ML Rockhold, X Chen, SR Waichler, KL Schuchardt, G Pau, VV Vesselinov, EA Porter, CJ Murray, MD Freshley, and I Gorton. 2012. "Simulation of Technetium-99 migration at the Hanford BC Cribs Site Using High Performance Computing." *Presented at Computational Methods in Water Resources,* Champaign-Urbana, IL on June 20, 2012.

Freedman VL, ML Rockhold, X Chen, KL Schuchardt, SR Waichler, G Pau, VV Vesselinov, EA Porter, CJ Murray, MD Freshley, and I Gorton. "Uncertainty Assessment at BC Cribs at Hanford Using the ASCEM Toolset." Presented at the *Washington State Hydrogeology Symposium,* Tacoma, WA on April 23, 2013.

Freshley MD and SS Hubbard. 2012. "Advanced Simulation Capability for Environmental Management (ASCEM): Application for Natural Attenuation at the Savannah River Site." *REMTEC Remediation Technology Summit*, March 4-8, Westminster, CO.

Moulton JD, CI Steefel, S Yabusaki, K Castleton, TD Scheibe, EH Keating, and VL Freedman. "Hierarchical testing with automated document generation for Amanzi, ASCEM's subsurface flow and reactive transport simulator." *2013 American Geophysical Union Fall Meeting*, December 9-13, San Francisco, CA.

Seitz RR, MD Freshley, P Dixon, SS Hubbard, V Freedman, G Flach, B Faybishenko, I Gorton, S Finsterle, JD Moulton, CI Steefel, and J Marble. 2013. "Advanced Simulation Capability for Environmental Management – Current Status and Phase II Demonstration Results." In *Waste Management Symposia 2013*, February 24-28, 2013, Tucson, AZ.

Spycher N, S Bea, H Wainwright, S Mukhopadhyay, J Christensen, W Dong, S Hubbard, J Davis, and M Denham. 2012. "Integrating Geochemical, Reactive Transport, and Facies-Based Modeling Approaches at the Contaminated Savannah River F-Area." *Goldschmidt 2012*, Montreal, Canada.

Scheibe T, M Freshley, S Hubbard, D Moulton, and P Dixon. 2013. "Advanced Simulation Capability for Environmental Management" (Poster). *2013 TER-SBR Joint Investigators Meeting,* May 13-15, Potomac, MD

Scheibe T. 2013. "Development of Enhanced Workflow Tools for Subsurface Modeling." *2013 TER-SBR Joint Investigators Meeting*, May 13-15, Potomac, MD.

Dixon P, P Black, M Freshley, B Robinson, T Stockton, D Moulton, K Gerdes, J Marble, R Seitz, and T Scheibe. 2013. "Advanced Simulation Capability for Environmental Management – Current Status and Future Applications." *Technical Publication in the Conference Proceedings for ICEM 2013 Meeting, ICEM2013-96152*, September 10, 2013 Brussels, Belgium.

U.S. DEPARTMENT OF ENERGY

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